CR- 109158

P. 33

THE NASA SCHEDULING SYSTEM

Scheduling in the Apollo Program
(Part 1 of 6)

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July, 1969

Scheduling in the Apollo Program

Project management differs from traditional forms of management in industry primarily in terms of planning and control systems required for successful task accomplishment. In industry and other organizations such as hospitals, schools, and several government agencies, the management function revolves around the efficient and effective utilization of resources to meet the objectives of the organization. In such organizations survival is of paramount importance as an objective. Thus the production of products and/or services is viewed as a continuing process over time.

In project management the production of products and/or services has a finite end point in time; the completion date of the project. As such, project organizations do not perpetuate themselves but are created for a specific mission and disbanded at the completion of the mission. All activities required for the completion of the mission must be coordinated over time to assure that each phase in the life cycle of the project is completed on schedule. Since these phases are usually sequential, a delay in one phase will often delay the completion of the entire project.

For this reason, a number of management planning activities are required to minimize total project slippage:

1. The objectives of the project should be specified and time phased.
2. Target dates should be established for the major phases of the project.
3. The major phases should be evaluated and subordinate target dates established for subordinate activities which are required for the completion of each phase.
4. Detailed analysis of sequential activities and events should be

undertaken to assure that no significant interrelationships among subordinate activities have been overlooked.

5. A control system should be developed to provide feedback information to management on the completion of subordiaate activities as well as problems which may adversely impact the overall schedule. If possible such problem detection and identification should take place as quickly as possible so that corrective action may be taken to avert a schedule slippage.[1]

Major Phasing of the Apollo Program

An example of phase definition in project management can be found in the broad definitions of program phasing developed for the Apollo Program.[2] The seven major phases are as follows:

a. "Development of the Uprated Saturn I launch vehicle and the Apollo Spacecraft command and service modules (CSM).

b. Unmanned flights for development of the Saturn V launch vehicle and verification of the adequacy of the command module during return through the earth's atmosphere at the speed of return from the moon.

c. Development of the lunar module (LM), through unmanned flights in earth orbit, boosted by the Uprated Saturn I launch vehicle.

d. Manned earth-orbital flights of the Apollo spacecraft CSM in earth orbit, boosted by the Uprated Saturn I launch vehicle, to verify crew operations for mission durations up to ten days.

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[1]David L. Cleland and William R. King, Systems Analysis and Project Management, New York: McGraw-Hill Book Company, 1968, Chapter 12, Project Planning and Control, pp. 264-288.

[2]NASA-Apollo Program Management, Washington, D. C.: NASA Apollo Porgram Office, Vol. 1, December, 1967, pp. 1-5.

e. Manned earth-orbital flights of the Apollo spacecraft CSM, boosted by the Saturn V, to verify the functional capability and operability of all elements of the spacecraft system.

f. Lunar mission development, through simulations of the total mission in earth orbit along the actual time line of a lunar mission. These missions employ the fully configured Apollo-Saturn V flight hardware.

g. Lunar missions, including lunar exploration and safe return to earth."

These phases have been accomplished and the overall project schedule has been maintained despite problems encountered in the three primary components of the mission; the LM, CSM, and Saturn V launch vehicle. Major schedule modifications resulted from the AS-204 spacecraft fire, the pogo effect encountered in the Saturn V launch vehicle, and difficulties with the lunar module.

Decisions made at NASA Headquarters, field centers, and contractor companies overcame these slippages through intensive efforts to solve the problems. These decisions, of course, resulted in new schedules which reflected the changed conditions. This form of adaptive scheduling is another difference between project management scheduling and scheduling in traditional organizations where schedules are less frequently modified.

Translation of Major Phases into Mission Launch Dates

After the major phasing has been accomplished, the next task is to translate these objectives into specific mission objectives. That is, each flight is planned to yield specific research results and the scheduling function at the phase level (calibrated in years) is reduced to mission schedules (calibrated in months). An example of this level of scheduling is depicted in Figure 1, the Apollo Launch Readiness Working Schedule.

This schedule reveals the projected timing of several missions utilizing the Saturn 1-B and the Saturn V. The particular schedule in Figure 1 is dated November 20, 1968. It indicates the launch dates of the last two Saturn 1-B launches (AS 204 and AS 205) which verified the operation of the CSM in earth orbit. Also scheduled are the following missions:

AS 501 the first launch of the Saturn V launch vehicle

AS 502 an unmanned launch of the Saturn V

AS 503 the manned launch of a Saturn V involving circumlunar navigation and testing of the CSM in the lunar environment (Apollo 8).

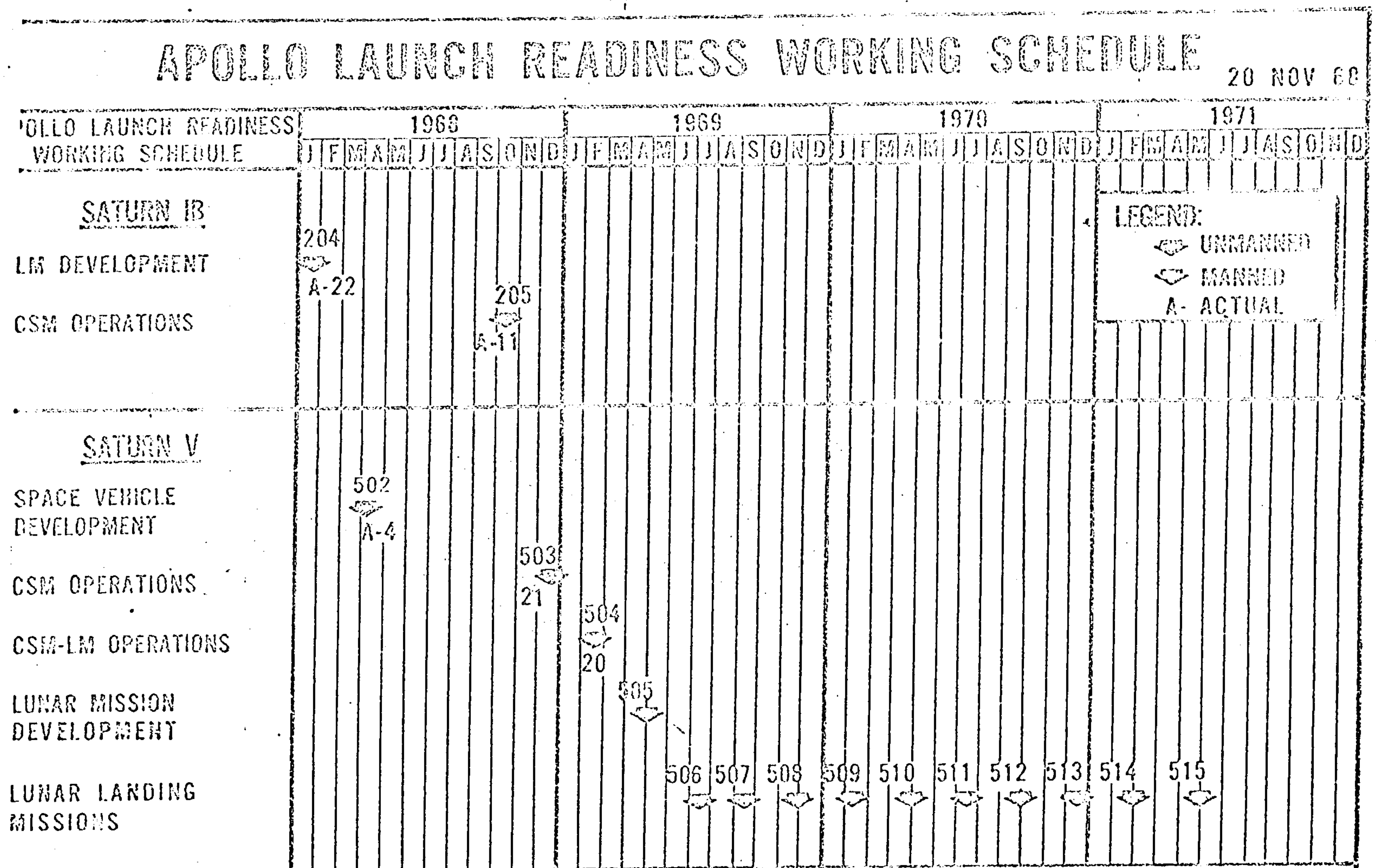
AS 504 the manned launch of a Saturn V to test the CSM and particularly the LM in earth orbit. This mission indicated that the LM and CSM could separate, the LM could be flown successfully as a space vehicle, and could separate its ascent and descent stages, rendezvous and dock with the CSM (Apollo 9).

AS 505 the manned launch of a Saturn V to test the CSM and LM in the lunar environment. This mission duplicated many of the tests in Apollo 9 with respect to the CSM/LM operations but these tests were carried out in orbit around the moon. (Apollo 10)

AS 506 the manned launch of a Saturn V to achieve the major objective of the Apollo program, a lunar landing followed by the safe return of the astronauts to Earth. (Apollo 11)

AS 507-515 represent scheduled missions through 1969, 1970, and 1971. The launches are scheduled on two month centers which may involve alternating on launch pads A and B. Before this segment of the schedule can be activated, however, the cycle of project phasing must be re-initiated to develop specific mission objectives beyond the lunar landing, AS 506 (Apollo 11). These may involve additional lunar landings or programs associated with Apollo Applications which represents a program following the completion of the Apollo program.

Figure 1



IOTE: AS-501 LAUNCHED 9 NOV 1967

THIS DOCUMENT WILL BE MADE AVAILABLE ONLY TO THOSE PERSONS REQUIRING THE INFORMATION IN THE PERFORMANCE OF THEIR OFFICIAL DUTIES. ACCESS TO THIS MATERIAL BY OTHERS OUTSIDE THE AGENCY WILL BE AT THE DISCRE ON OF THE ASSISTANT ADMINISTRATOR FOR PUBLIC AFFAIRS

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Development of Launch Schedules

Although major program phasing is required in project management, the feedback on accomplishment of each phase is insufficient for timely management control. To achieve this control, schedules must be established for subordinate activities.

In NASA these subordinate activities are time phased in the schedules for particular flights of missions. These missions, in turn, are designed to support the accomplishment of major program phases. Each mission is composed of controlled and supporting milestones defined as follows:[3]

"Controlled milestones are those milestones which are of major significance to a program. Changes in scheduled completion dates of controlled milestones must be approved by cognizant Office of Manned Space Flight Program Directors."

"Supporting milestones are milestones which can be rescheduled at the discretion of the individual having schedule responsibility. No approval of such rescheduling actions will be required from cognizant Office of Manned Space Flight Program Directors."

An examination of a typical mission schedule reveals the level of detail represented by such milestones. Over a time scale, bar charts are constructed to depict the scheduled time allowed for several key activities. Among these are the following:

1. Factory checkout of the CSM, delivery to Kennedy Space Center (KSC), and mechanical mating to the launch vehicle in the Vehicle Assembly Building (VAB).

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[3] Program Scheduling and Review Handbook, Washington, D. C.: NASA OMSF Program Control, NHB 2330.1, October, 1965, pp. 14-15.

2. Factory checkout of the LM, delivery to KSC, and mating in the VAB.
3. Delivery of the three stages of the launch vehicle (S-IC, S-II, and S-IVB) as well as the instrument unit (IU) to KSC, stacking of the Saturn V in the VAB and mating with the LM and CSM.
4. Activities required in the VAB to stack the hardware and check it out.
5. Ground tests, docking tests, and other critical test procedures.
6. Delivery, checkout, and final preparation of computer programs internal to the LM and CSM (known as flight ropes).
7. Facility preparation which may involve the mobile service structure (MSS), launch umbilical tower (LUT), service arms, safety devices, etc.
8. Launch pad preparation and checkout.
9. Development of mission operations for launch control.
10. Transfer of the stacked vehicle to the pad, final checkout, and launch.[4]

At this level of detail, the coordination of sequenced activities is highlighted. A delay in any of these related streams of events can delay the entire mission if it cannot be corrected. At this stage, scheduling becomes critical since the launch must take place at a particular time of the month to hit the lunar window. If the schedule slips, about one month will pass before the next lunar window opens.

The interrelationships of activities is indicated in Figure 2 which represents a schedule for mission development. An actual schedule is not portrayed due to the restricted nature of the information.

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[4] For more detailed analysis of actual schedules for particular missions, see the Apollo Program Directive 4 series, "Apollo Program Schedule and Hardware Planning Guidelines and Requirements" NASA Headquarters, Washington, D. C.: OMSF, APO Program Control (restricted document).

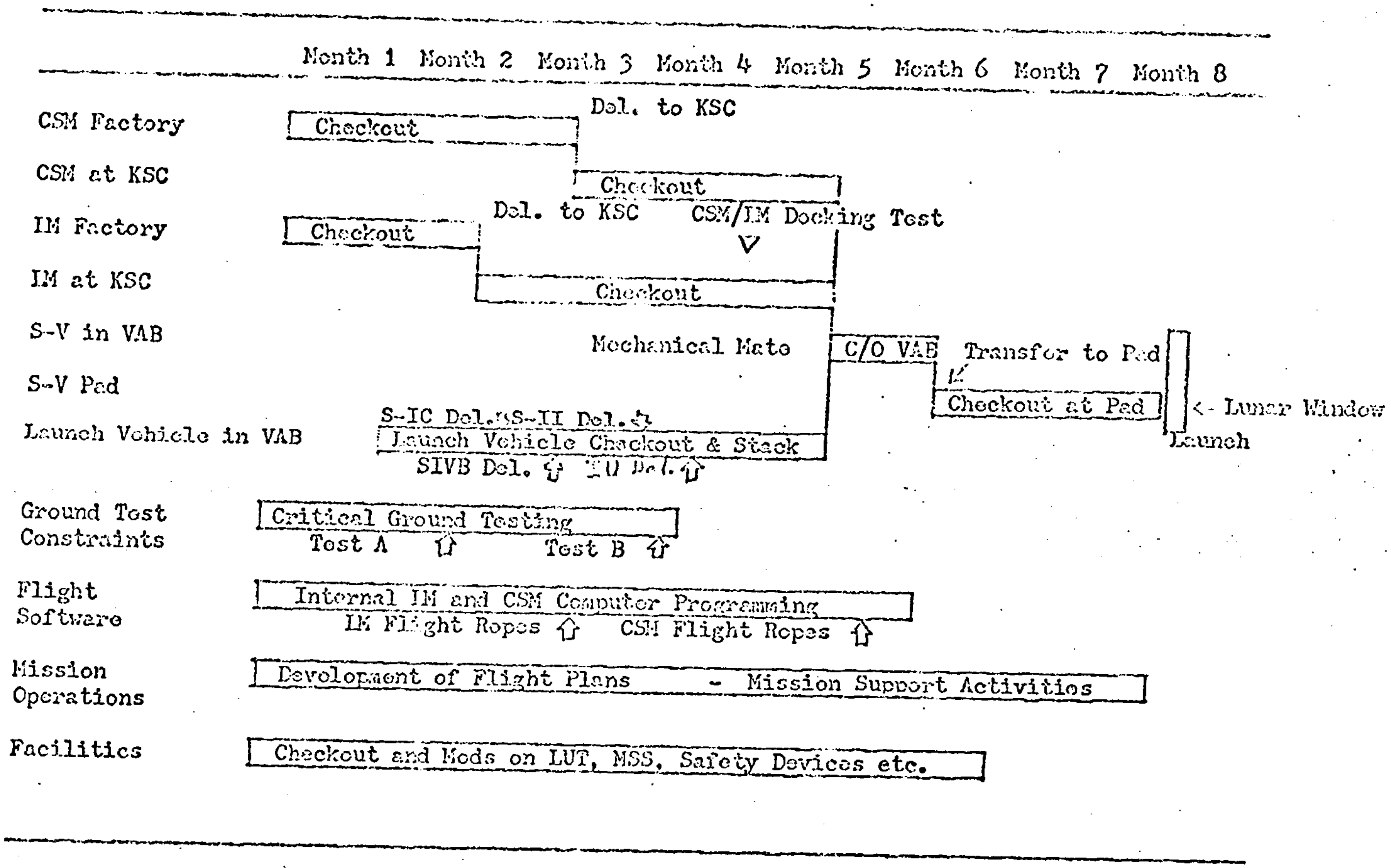
From Figure 2 it can be seen that the CSM, LM, S-IC, S-II, S-IVB, and IU must be checked out at the factories, delivered to KSC, and checked out at the Cape to assure that they will all be ready for stacking at the proper time in the VAB. The stack sequence is as follows: S-IC, S-II, S-IVB, IU, LM, CSM, and launch escape system. This sequence is illustrated in Figure 3, an exploded diagram of both the Uprated Saturn 1 and Saturn V space vehicles.

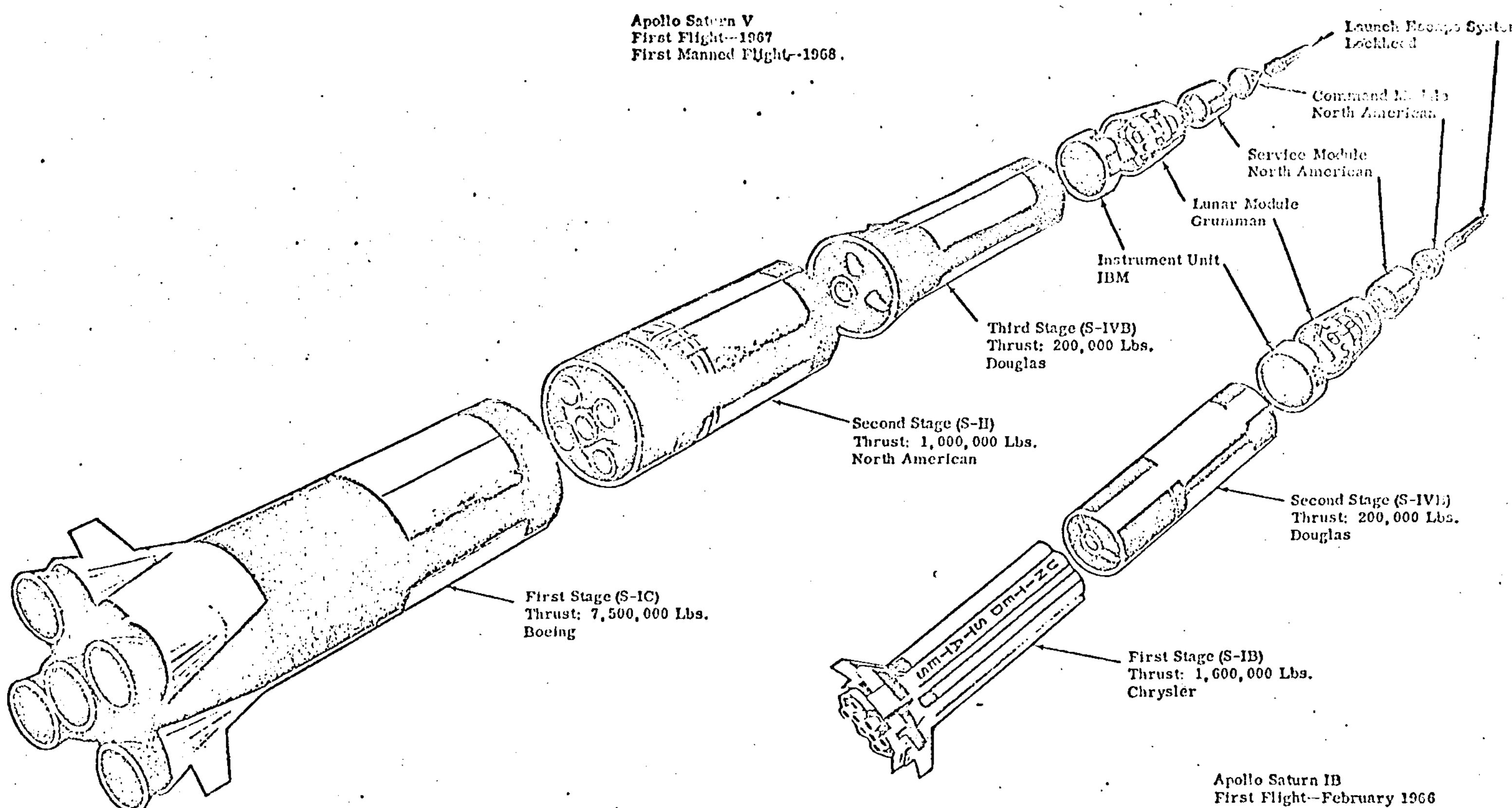
A delay in the acquisition and checkout of any of these components can delay the critical interface of mechanical mating in the VAB as depicted in Figure 2. An example of this occurred in the Apollo 8 mission which was redefined to exclude a test of the lunar module due to problems in that component at that point in time.

To meet the requirements of the program phase regarding lunar mission development in earth orbit, a LM was flown on the Apollo 9 mission to test LM/CSM separation and docking as well as the operation of the LM in space. This example of a mission redefinition is one indication of how NASA successfully accomplished a major phase within the overall schedule while dramatically altering the mission schedule to include a circumlunar mission (Apollo 8) in place of the earth orbit test of the CSM/LM.

Figure 2

Apollo Mission Development Schedule





3
Figure A-8. Apollo Space Vehicles

Such work arounds are common in project management especially in complex tasks operating at the fringe of the state of the art. The Apollo program represents such an environment. The management experience in NASA with respect to these conditions leads to two conclusions concerning scheduling. First, in project management, scheduling must be developed as a flexible and dynamic management system subject to significant change as problems arise. This is in contrast to the relatively fixed schedules found in industry. Second, the scheduling system must be designed to guarantee that critical interrelationships among activities are explored fully. In industry many examples can be found of schedules which relate to single lines of sequential events such as assembly line scheduling in manufacturing plants.[5] In NASA project management, however, the large number of interrelated activities create an environment in which a schedule slippage of one component in one contractor's organization can delay an entire mission.

Major Project Management Schedules

The development of launch schedules in a program as complex as Apollo requires that schedule authority and responsibility be centralized. The activities of the three field centers, Manned Spacecraft Center (MSC), Marshall Space Flight Center (MSFC), and Kennedy Space Center (KSC), as well as the activities of the prime contractors and subcontractors are

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[5]For examples of scheduling systems used in industry see: J.E. Biegel, Production Control: A Quantitative Approach, Englewood Cliffs, J. J., Prentice-Hall, Inc., 1963, Ch. 9; R. H. Bock and W. K. Holstein, Production Planning and Control, Columbus, Ohio, Charles E. Merrill Books, Inc., 1963, Ch. 5; S. Eilon, Elements of Production Planning and Control, New York, the Macmillan Company, 1962, Ch. 3; J. W. Gavett, Production and Operations Management, New York, Harcourt Brace and World, Inc., 1968, Ch. 16; and R. J. Hopeman, Production: Concepts Analysis, Control, Columbus, Ohio, Charles E. Merrill Book Co., 1965, Chs. 11 and 12.

integrated at NASA headquarters. Any schedule changes which may effect a scheduled launch date must be approved by the Associate Administrator for Manned Space Flight at the Office of Manned Space Flight (OMSF) level.[6]

Those schedule changes which may affect a controlled milestone[7] may be approved at the next lower level in the organization, i.e., the Director of the Apollo Program at the Apollo Program Office (APO) level.[8] Beyond the schedule changes which may impact launch dates or controlled milestones, schedule responsibiliiy and the authority to modify schedules passes to the field center directors. These directors, in turn, normally assign schedule responsibility and authority to program and project managers at the center level.

Schedules developed and managed at this level are associated with major project activities and hardware. For example, at MSFC, project schedules are developed for major hardware items managed by project managers including the S-IC, S-II, and S-IVB stages as well as the IU. At MSC, similar project oriented schedules are managed by the project managers responsible for the LM and CSM. In addition to hardware, schedules are developed and managed for support activities such as crew training, flight operations, and medical research and operations. Examples of such schedules appear in Figures 4 through 8.

Figures 4 and 5 are representations of manufacturing and delivery schedules for several CSM's and LM's. They reveal the planned sequence of structural assembly, systems installation, storage, checkout, and delivery from the manufacturer. Where applicable, other activities may also be

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[6]Program Scheduling and Review Handbook, _op. cit._, p. 3.

[7]_Ibid._, p. 14.

[8]_Ibid._, p. 3.

reflected including systems removal, modification of hardware, and testing. Such schedules reflect those activities which end with delivery to NASA. At this point they are integrated with the launch schedules. The end point on schedules such as those depicted in Figures 4 and 5 thus become the starting points on launch schedules as depicted in Figure 2.

A particular field center also establishes project oriented schedules for the variety of tests conducted on hardware and software, for example, the test sequence for a series of spacecraft.

Figures 6, 7, and 8 are representations of schedules for support activities. Figure 6 deals with flight crews. Such schedules cover a variety of important activities including crew assignment to a mission, preparation of flight plans, development of the mission training program, pre-flight training, etc. External interfaces are also indicated which impact the activities of those responsible for crews and crew equipment.

The schedule in Figure 7 is a representation of support activities in the area of flight operations. Such schedules cover the development of trajectories, mission constraints, alternate mission plans, preparation for recovery of the spacecraft, and a variety of flight control activities including mission simulation.

Figure 8 is a representation of a medical research and operations schedule. It includes activities such as medical review and approval of flight plans, preparation of medical mission rules, preparation of medical requirements plans, and primary and backup crew examinations.

The schedules described above represent the level of detail which is reviewed at the field center and is submitted for purposes of schedule integration at the APO and OMSF levels. Numerous schedules exist at the project level covering both hardware and supporting activities. The common reference point is the launch schedule for a particular mission and therefore these more detailed schedules reflect a strong mission orientation. This is particularly evident in the support scheduling while hardware managers must also plan far ahead to assure that hardware for which they are responsible will be available for successive missions. This planning may require a lead time of over two years from structural assembly through checkout.

5 YEAR

SCHEDULE RESPONSIBILITY K. S. KLEINKNECHT

STATUS RESPONSIBILITY R. C. HOOD

MANNED SPACE FLIGHT SCHEDULE
SPECIAL SUMMARY
APOLLO, CSM MFG & DEL SCHED

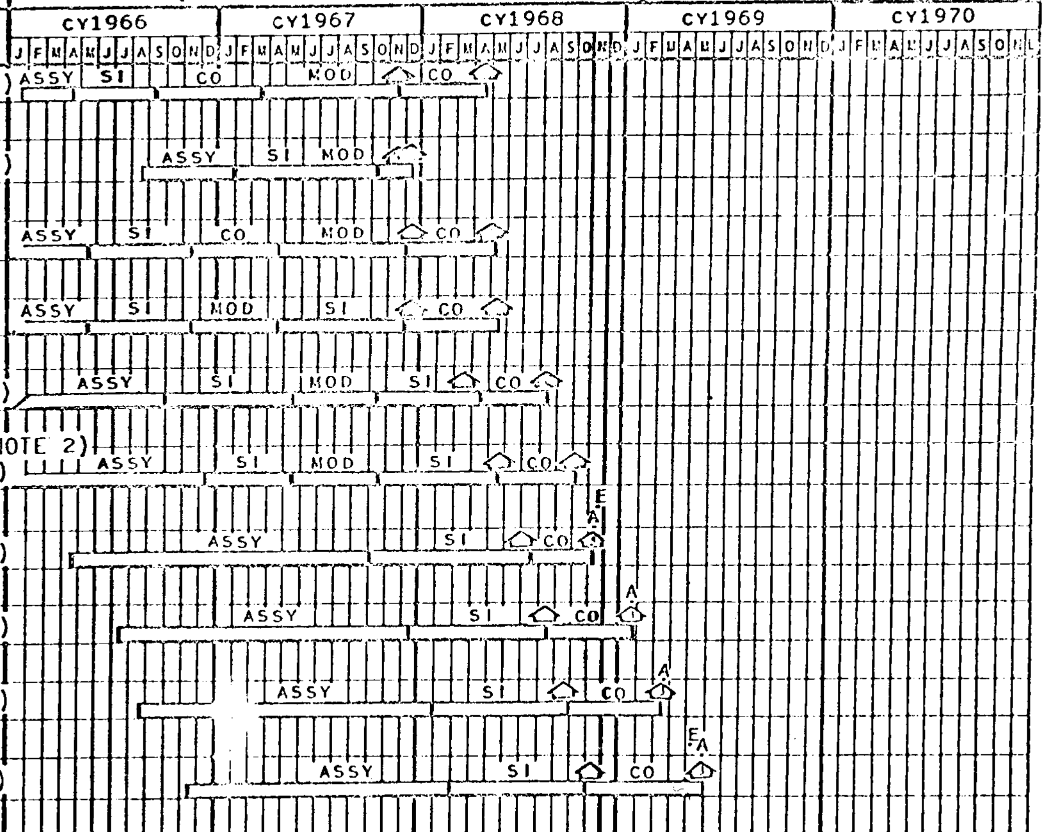
2 LEVEL

CONTRACTOR: NR (NAS 9-150)

PROJECT:
SCHD. NO:

ORIGINAL SCHEDULE APPROVAL FEB 8, 1963 (DATE)
LAST SCHEDULE CHANGE 9/16/1968 (DATE) (NO.) (INITIALS)
STATUS AS OF OCT 31,1968 (DATE) (INITIALS)

	MILESTONES
1	CSM 2TV-1 THERMAL-VAC TEST(MSC)
2	
3	CSM 105/AV ACOUS-VIB TESTS(MSC)
4	
5	SM 101 SPACECRAFT MISSION(KSC)
6	
7	CM 101 SPACECRAFT MISSION(KSC)
8	
9	CSM 103 SPACECRAFT MISSION(KSC)
10	
11	CSM 104 SPACECRAFT MISSION(KSC)
12	
13	CSM 106 SPACECRAFT MISSION(KSC)
14	
15	CSM 107 SPACECRAFT MISSION(KSC)
16	
17	CSM 108 SPACECRAFT MISSION(KSC)
18	
19	CSM 109 SPACECRAFT MISSION(KSC)
20	



NOTES 1. SHADED AREA REPRESENTS STORAGE TIME.
2. CSM 104 DELIVERED TO KSC OCT 4, 1968.

ASSY - STRUCTURE ASSEMBLY
SI - SYSTEMS INSTALLATION
CO - FACTORY CHECKOUT
SR - SYSTEMS REMOVAL

STOR-STORAGE
MOD -MODIFICATION
TSTG-TESTING

NASA FORM 755 DEC. 62, REVISED 9-63

11-2-44

Fig 4

5 YEAR

MANNED SPACE FLIGHT SCHEDULE
SPECIAL SUMMARY
APOLLO MFG AND DELIVERY SCHEDULE
LTA/LM

3 LEVEL

SCHEDULE RESPONSIBILITY C. H. BOLENDER

STATUS RESPONSIBILITY O. G. MORRIS

CONTRACTOR: GAEC (NAS 9-1100)

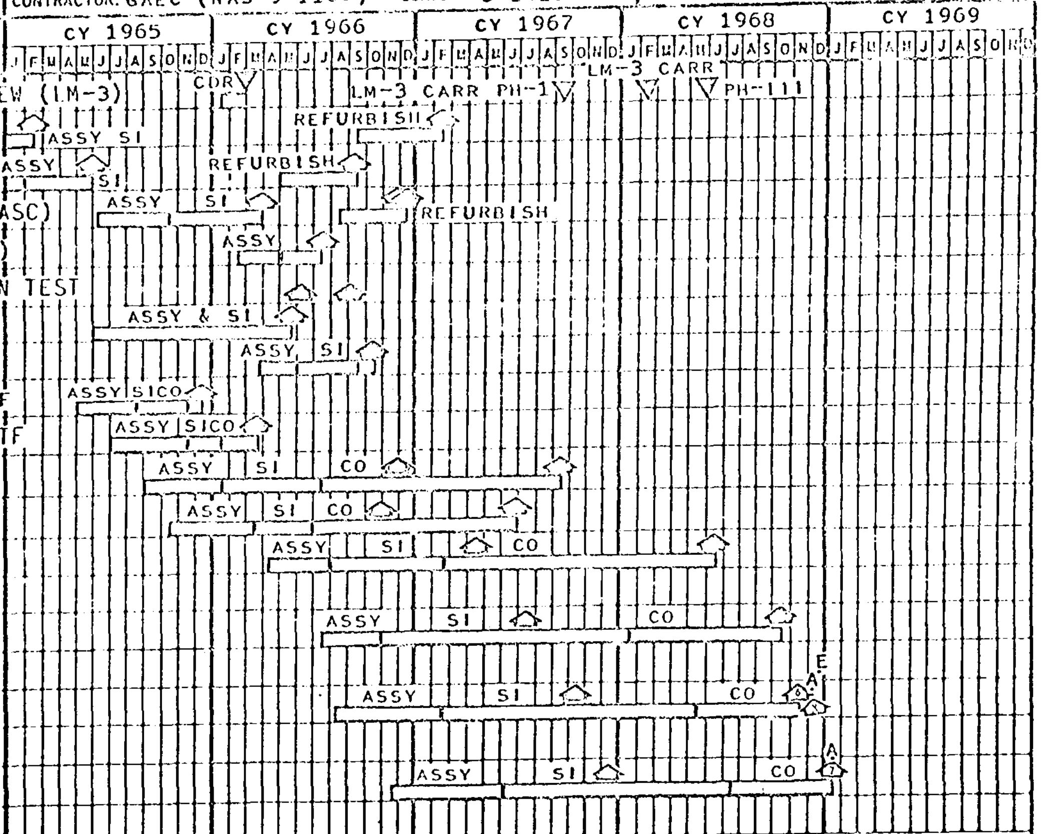
PROJECT: APOLLO
SCHD. NO: 3-1413-2

ORIGINAL SCHEDULE APPROVAL FEB 8, 1963 (DATE)

LAST SCHEDULE CHANGE JUL 65 (DATE) (NO.) (INITIALS)

STATUS AS OF OCT 31, 1968 (DATE) (INITIALS)

	MILESTONES
1	LM HARDWARE INSPECTION & REVIEW (LM-3)
2	LTA-2 DYNAMIC TEST MSFC
3	LTA-10 LEM/SLA STRUCT TEST NAA
4	LM-2 THERMAL VACUUM TEST GAEC(ASC)
5	LTA-3 STRUCTURAL TEST GAEC(ASC)
6	DUMMY LTA TO MSFC FOR SAT V DYN TEST
7	LTA-1 HOUSE SPACECRAFT #1 GAEC
8	LTA-5D PROP(DSC) TEST WSTF
9	PA-1 ASCENT PROPULSION RIG WSTF
10	PD-2 DESCENT PROPULSION RIG WSTF
11	LTA-8 THERMAL VACUUM MSC
12	LM-1 UNMANNED KSC
13	LM-3 MANNED KSC
14	
15	LM-4 MANNED KSC (NOTE 1)
16	
17	LM-5 MANNED KSC
18	
19	LM-6 MANNED KSC
20	



NOTES 1. DESCENT STAGE WAS SHIPPED TO KSC ON 10/10/68; ASCENT STAGE ON 10/15/68.

ASSY - STRUCTURAL ASSEMBLY
SI - SUBSYSTEMS INSTALLATION
CO - FACTORY CHECKOUT

(PAGE 1 OF 2)
11-2-74

MSC Form 965E (Aug 68)

Fig 5

5 YEAR
MANNED SPACE FLIGHT SCHEDULE
ORIGINAL SCHEDULE APPROVAL FEB 8, 1963 (DATE)
JUL 65

3 YEAR

SCHEDULE RESPONSIBILITY D. T. Gregory for D. K. SLAYTON

STATUS RESPONSIBILITY W. J. North
W. J. NORTH

MANNED SPACE FLIGHT SCHEDULE
CREW & CREW EQUIPMENT FLIGHT READY
AS-504

CONTRACTOR:

PROJECT SCHD. NO.

LEVEL

ORIGINAL SCHEDULE APPROVAL ________ (DATE)

LAST SCHEDULE CHANGE ________ (DATE) (NO.) (INITIALS)

STATUS AS OF OCT 31,1968 (DATE) (INITIALS)

CY 1967 | CY 1968 | CY 1969 — J F M A M J J A S O N D (each year)

	MILESTONES	
1	CREW & CREW EQUIP FLT READY	
2	CREW ASSIGNED	
3	PREPARE PRELIM FLT PLAN (NOTE 1)	
4	PREPARE FINAL FLT PLAN	
5	PRELIM MISSION TRNG PROG ISSUED	
6	PREPARE OPERATION HDBKS (VOL II)	
7	FINAL CREW CHECKLIST ISSUED	
8	PROCEDURES DEV SIMULATOR (UPDATE)	
9	AMS-HOUSTON (UPDATE)	
10	AMS-CAPE (UPDATE)	
11	LMS-HOUSTON (UPDATE)	
12	LMS-CAPE (UPDATE)	
13	CREW PRE-FLIGHT TRAINING	
14		EXTERNAL INTERFACES
15	MISSION REQUIREMENTS AVAIL	(AUGUST 1966)
16	PRELIM REFERENCE TRAJ AVAIL	(FEBRUARY 1967)
17	REFERENCE TRAJ AVAIL (REV)	
18	SPACECRAFT OPERATION TRAJ AVAIL	
19	CREW PERSONAL EQUIPMENT READY	
20		

NOTES 1. DELAY RESULT OF CHANGE IN RENDEZVOUS.

Fig 6

NASA FORM 793 REV. SEPT. 63

1 YEAR

SCHEDULE RESPONSIBILITY *[signature]* for C. C. KRAFT

STATUS RESPONSIBILITY *S. A. Way* S. A. WAY

MANNED SPACE FLIGHT SCHEDULE
FLIGHT OPERATIONS
AS-503 (C') S/C 103/LTA-B

2 LEVEL

PROJECT MISS OPS
SCHD. NO.

CONTRACTOR:

ORIGINAL SCHEDULE APPROVAL FEB 29,1968 (DATE)
LAST SCHEDULE CHANGE (DATE) (NO.) (INITIALS)
STATUS AS OF OCT 31,1968 (DATE) *[initials]* (INITIALS)

CY 1968

	MILESTONES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	FLIGHT OPERS PREPARATION COMP												
2	MISSION PLANNING & ANAL COMP												
3	PRELIM MISSION PROFILE ISSUED	COMPLETE											
4	PRELIM REFERENCE TRAJ ISSUED	COMPLETE											
5	REFERENCE TRAJECTORY ISSUED												
6	OPER MISS CONSTRAINTS ISSUED												
7	OPER TRAJECTORY ISSUED												
8	OPER ABORT/ALTER MISS PLAN												
9	RECOVERY PREPARATION COMPLETE												
10	FLT CONTROL PLANNING COMPLETE												
11	OPS CONSTRAINTS FOR REF TRAJ	COMPLETE											
12	FCD DETAIL TEST OBJECTIVES REVIEW		COMPLETE										
13	SIM OPS PLAN	COMPLETE											
14	UPDATED DATA PACKAGES	COMPLETE											
15	FLT OPS PLAN												
16	SYSTEMS HANDBOOKS PUB & DEL												
17	PRELIM MSC LAUNCH MISSION RULES	COMPLETE											
18	PRELIM FLT PLAN MISSION RULES												
19	PRELIM FLT MISSION RULES												
20	START SIMULATIONS												

NOTES

NASA FORM 793 DEC. 62, REVISED 9-63

V-I-74/4

Fig 7

1 YEAR

SCHEDULE RESPONSIBILITY *A. D. Catterson, M.D.*
A. D. CATTERSON, M.D.

STATUS RESPONSIBILITY *W R Hawkins*
W. R. HAWKINS, M.D.

MANNED SPACE FLIGHT SCHEDULE
AS-503
MEDICAL RESEARCH AND OPERATIONS

2 LEVEL

CONTRACTOR:

PROJECT SCHD. NO.

ORIGINAL SCHEDULE APPROVAL ______ (DATE)

LAST SCHEDULE CHANGE ______ (DATE) (NO.) (INITIALS)

STATUS AS OF OCT 31, 1968 (DATE) ______ (INITIALS)

	MILESTONES	APR	MAY	JUN	JUL	AUG 1968	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1	MED REVIEW & APPROVAL OF FLT PLAN								∇				
2	PREP & SUBMIT MED MISSION RULES						∇						
3	MISSION RULES REVIEW								∇				
4	PREP & SUBMIT DOD MED PROG SUPPORT REQ'S			∇									
5	PREPARE & SUBMIT MEDICAL REQUIREMENTS PLAN						∇						
6	PRE-MISSION REVIEW CONFERENCE								∇				
7	KSC ALTITUDE CHAMBER TESTS						∇						
8	FLIGHT READINESS REVIEW								∇				
9	PRIME & BACKUP CREW MEDICAL EXAMINATIONS								∇				
10	PRIME CREW MEDICAL EXAMINATIONS									∇ 6 DEC 68			
11													
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NOTES

MSC FORM 005A (JAN 66)

V-1-75/1

Fig 8

1 YEAR

Although the schedules depicted in Figures 4-8 represent major project management schedules and are used by project managers to plan and control their projects, the actual operational management of hardware end-items requires even more detailed schedules within contractor's plants.

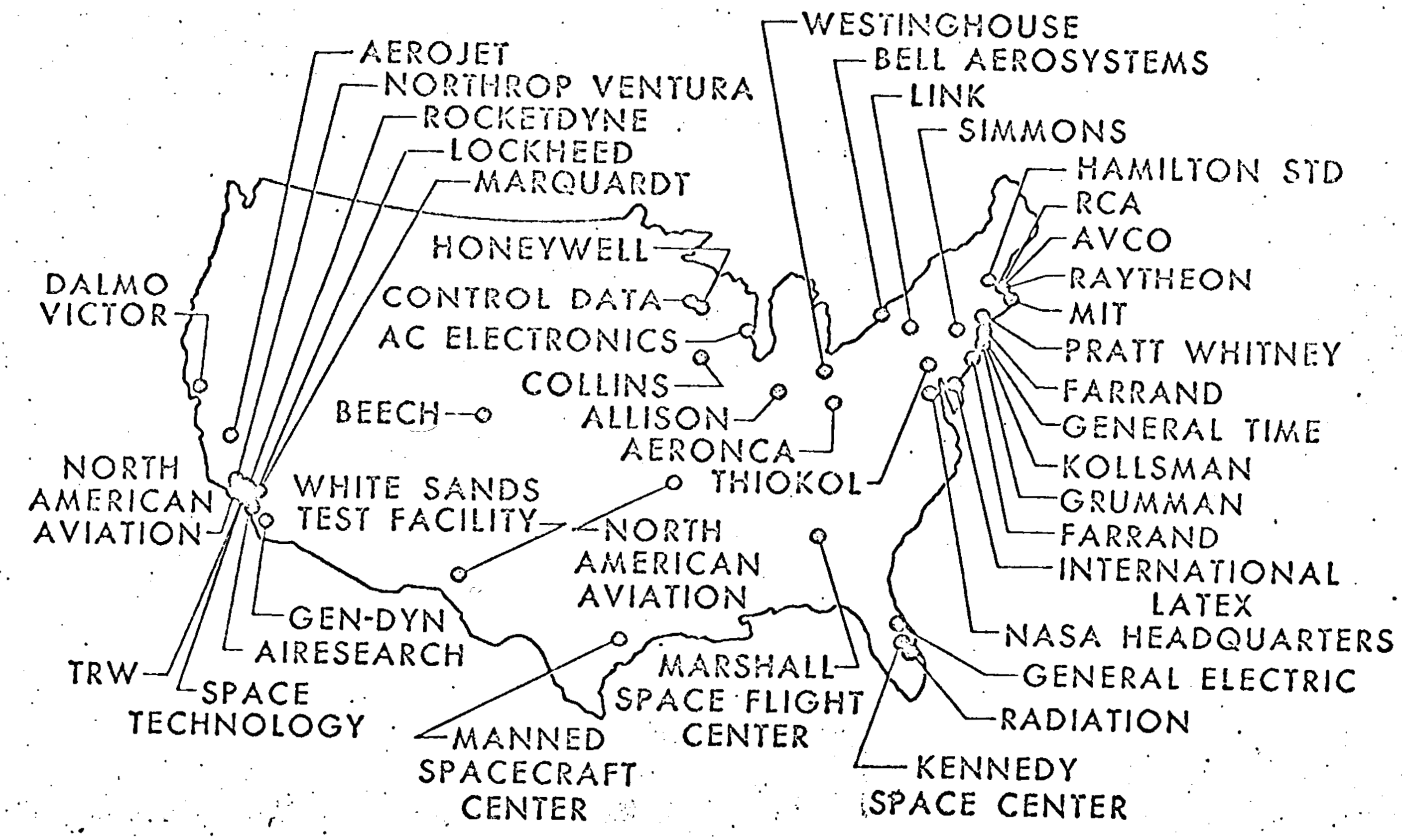
There are a large number of these contractors scattered throughout the United States as is depicted in Figure 9. One of the important functions of the major project management schedules is to coordinate the numerous activities at these geographically dispersed sites. The schedules developed by MSFC, MSC, and KSC represent plans and control systems to provide this coordination at the project level. These schedules, in turn, provide supporting information for decisions concerning the launch schedules. Ultimately the effective accomplishment of the launch schedules leads to accomplishment of the major phases of the Apollo program.

Figure 9

NASA-S-66-8932

APOLLO SPACECRAFT CONTRACTORS

CONTRACTS AND SUBCONTRACTS $5,000,000 AND OVER



Hardware End-Item Schedules

Within the prime contractor and subcontractor organizations, shcedules must be developed for the planning and control of operations which provide products and/or services for the Apollo program. While schedules within NASA tend to be project and mission oriented, the schedules in contractor plants tend to be oriented toward hardware end-items. This is a result of the NASA policy of letting contracts for components rather than for a total launch vehicle as has been done in certain Department of Defense contracts.

In addition to the LM produced by Grumman and the CSM produced by North American Rockwell, the Saturn V launch vehicle is produced by eight major contractors and hundreds of subcontractors. These major contractors are dispersed geographically as indicated in Figure 10. In some cases a single contractor has plants in widely separated locations. The contractors on the Saturn V are as follows:

S-1C stage	Boeing
S-II stage	North American Rockwell
S-IVB stage	Douglas
Instrument Unit	IBM
Ground Support Equipment	General Electric
Guidance components	Bendix and IBM
Ground computer	RCA
F1 and J2 engines	Rocketdyne

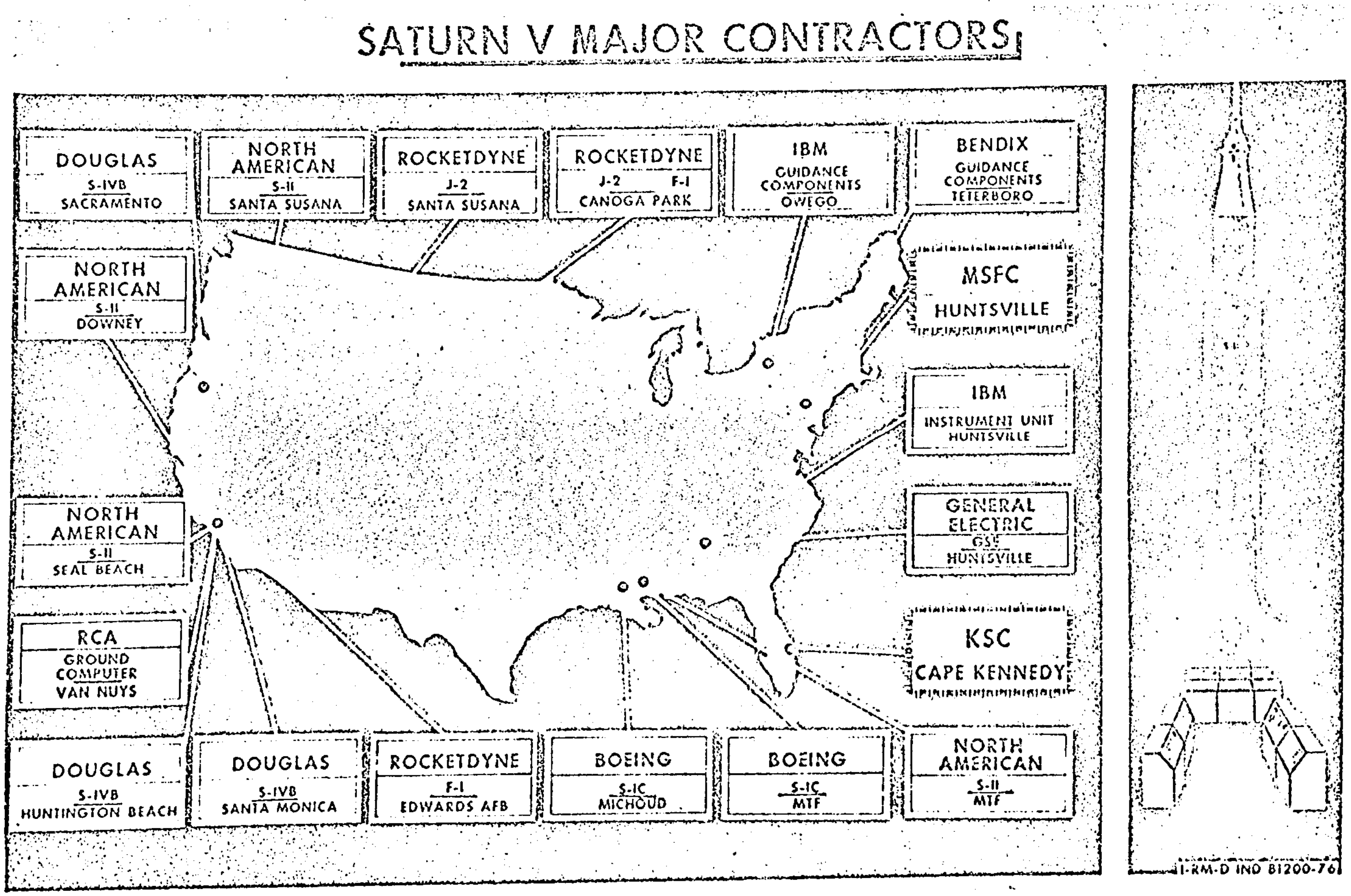


FIGURE 10 SATURN V MAJOR CONTRACTORS

It is the responsibility of these major contractors to manage their activities using schedules which support the major project management schedules. At MSFC, for example, NASA project managers in the Apollo program were organized into five key hardware divisions which interfaced with the prime contractors as follows:

S-1C Project Manager	to Boeing for S-1C stage
S-II Project Manager	to NAR for S-II stage
S-IVB Project Manager	to Douglas for S-IVB stage
IU Project Manager	to IBM for IU
GSE Project Manager	to GE for GSE

Each of thsse project managers monitors the performance of his respective contractor and through feedback from the contractor determines where problems have arisen or may arise. This information may be important enough to effect a controlled milestone in which case a decision must be made not at the MSFC level but at NASA headquarters in OMSF.

The project manager may also modify the performance of the contractor if a decision at Headquarters effects his contractor. In such a case he will monitor the changes in schedule required of the contractor due to the Headquarter's decision. As such the project manager stands at a critical interface between the program manager in NASA and the contractors which are providing the hardware.

At the contractor level, numerous hardware end-item schedules are maintained. In order to depict the nature of these detailed schedules, an example is drawn from Rocketdyne, the producer of the engines used in the Saturn V.

Figure 11 illustrates the functions of these engines in the Saturn V launch vehicle, the LM and CSM. Hardware end-item schedules are developed for each of these items. These indlude major contractor schedules for the following:

1. Launch escape engine
2. Twelve 93 pound thrust re-entry control engines
3. 3,500 pound thrust ascent engine on the LM
4. S-IVB ullage: two 72 pound thrust engines
5. S-IVB propulsion: one 225,000 pound thrust J2 engine
6. S-II ullage: eight 25,000 pound solid motors
7. S-II propulsion: five 225,000 pound thrust J-2 engines
8. S-IC propulsion: five 1,522,000 pound thrust F-1 engines

These engines represent a wide range in power and complexity from the small re-entry thrusters to the largest engines ever built, the F-1 engines on the S-IC stage.

At the contractor level the schedule emphasis is placed on providing these components at the time required by the contract. Although the NASA project manager is primarily concerned with the meeting of project schedules tied to particular launch schedules, a contractor, like Rocketdyne, must focus attention on more detailed matters, such as the balanced production of a series of components over time. Such a series is represented by the manufacturing of a number of J-2 engines.

The detailed consideration of schedules within a contractor organization is organized around the concept of a work breakdown structure as depicted in Figure 12. This structure is developed according to the components of which an assembly like the J-2 engine is composed: i.e., fuel turbopump, LOX turbopump, start system, etc.

These components, in turn, are composed of additional parts and subassemblies which are identified in detail in the work breakdown structure. For example, within a turbopump assembly, certain subassemblies

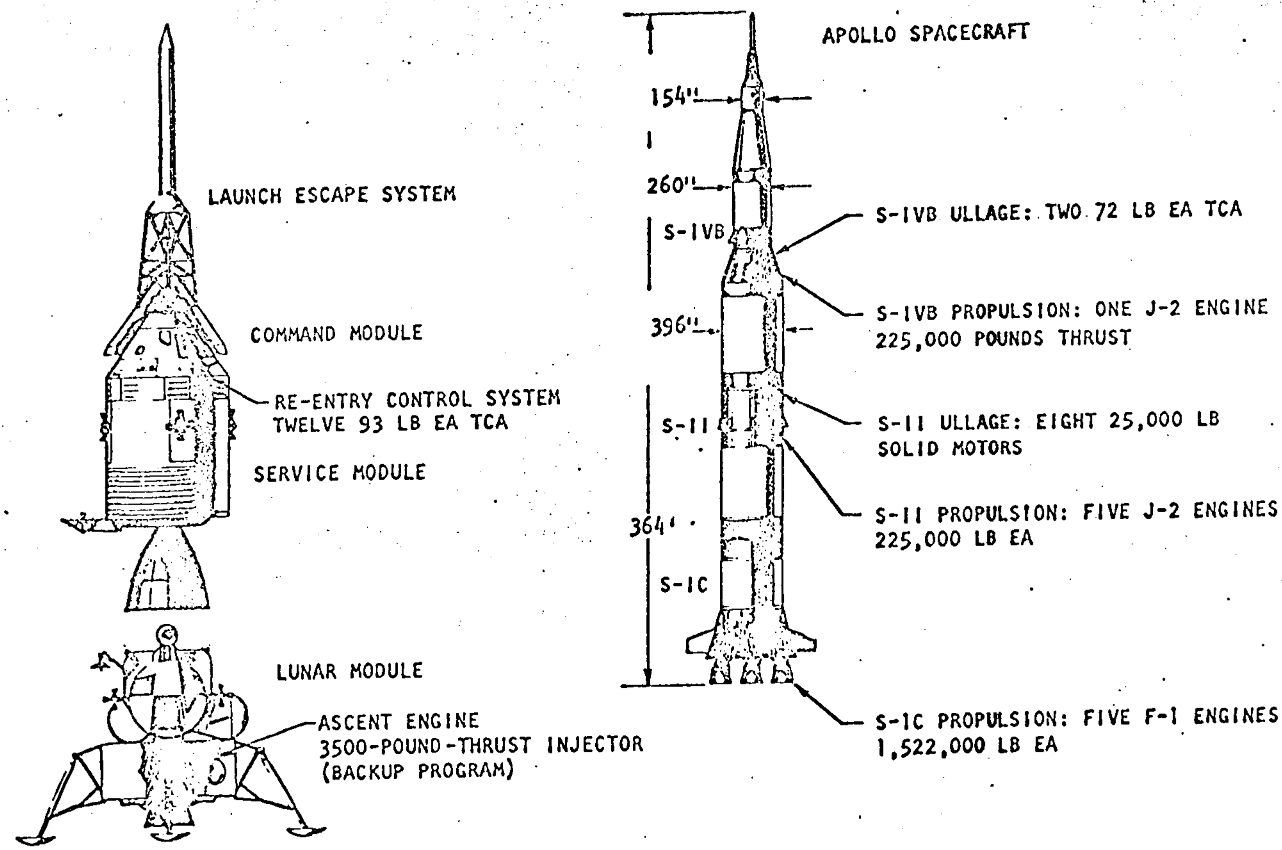


Figure ~~1-1~~ 11. Rocketdyne Propulsion Systems for Apollo/Saturn V Vehicles

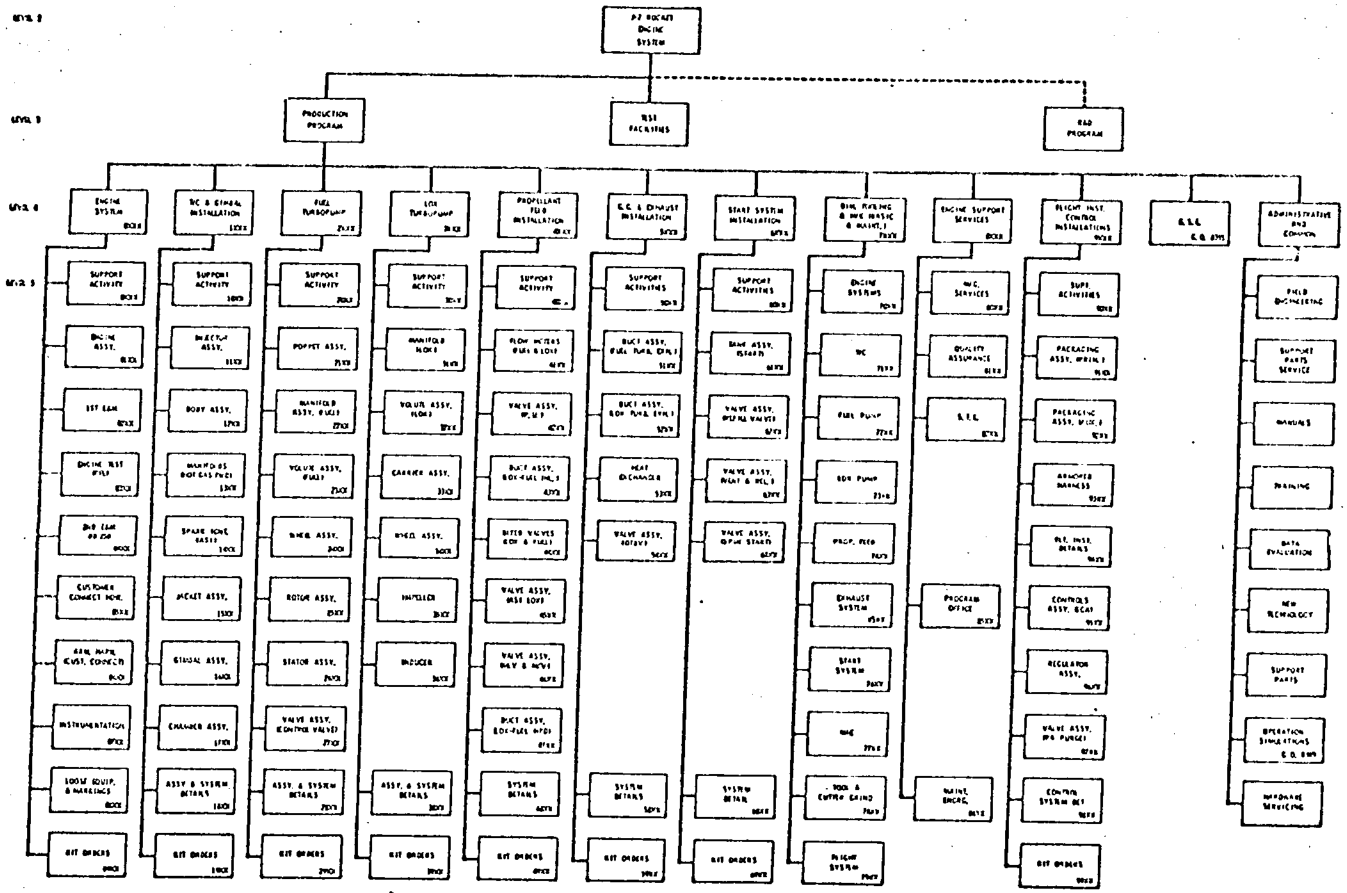


Figure 3-10. Appendix X J-2 Engine Work Breakdown Structure

are identified including manifold assembly, volute assembly, rotor assembly, stator assembly, control valve assembly, etc. Although Figure 12 indicates the detail of such a work breakdown structure for the J-2 engine, a clearer picture of the relationship of the parts and subassembly is indicated in the exploded drawing in Figure 13.

The hardware end-item schedule for the J-2 engine and schedules for all other major components in the Saturn V are developed to this level of detail to ensure effective operational planning and control in the production of the end items. A typical schedule for engines, in this case the F-1, is shown in Figure 14. The bar chart approach provides visibility on the plan of production as well as providing a focus on those activities which need attention in terms of coordination.

Summary

In this section we have reviewed scheduling in the Apollo program. It begins with the definition of the broad statements of objectives which define the goals of the program and their general sequence with a specified target date, i.e., completion prior to 1970. In Apollo seven major phases are defined.

These phases with their broad objectives are then developed into missions which have subordinate objectives leading to the accomplishment of a major phase. An important element of mission planning is the development of a launch schedule for these missions which provides more precise time targets for planning and control.

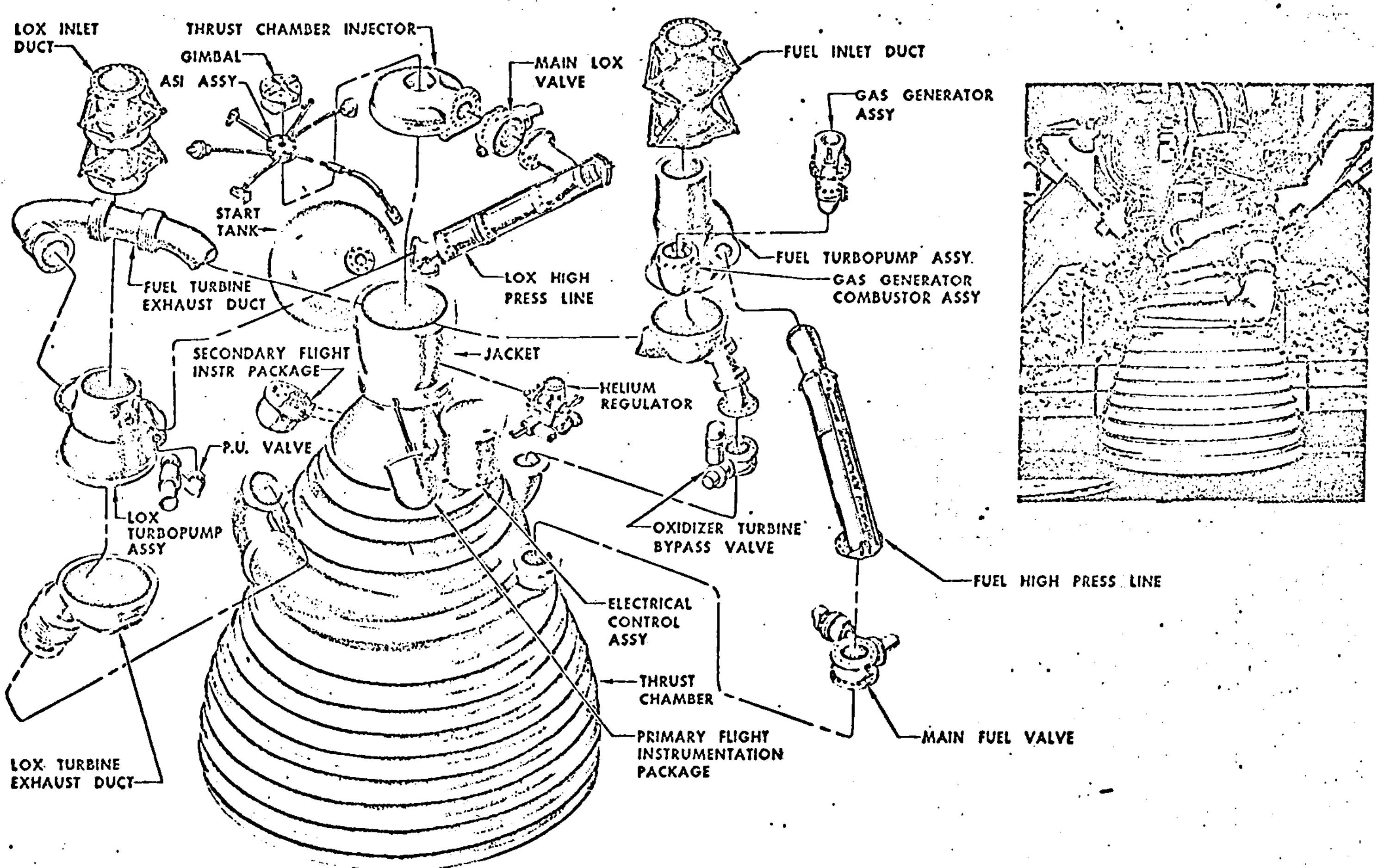


Figure 5-7. 12 J-2 Major Component Breakdown

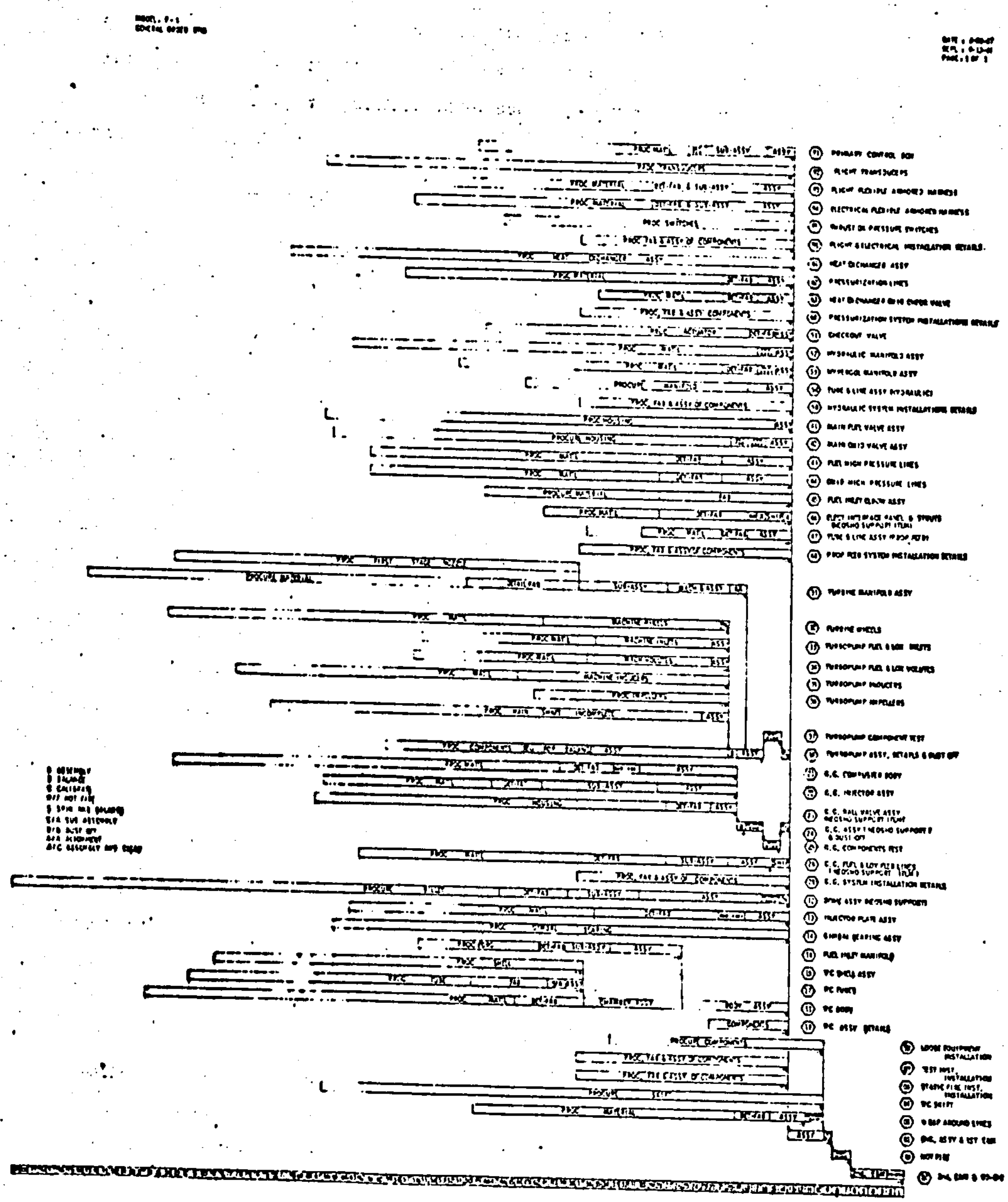


Figure 3-22. F-1 Master Schedule

Within the launch schedules, detailed planning and control take place at the project manager level to assure that the contractors deliver the major components for a mission on time. The major project management schedules developed for this purpose serve to coordinate the activities of contractors. By comparing field center schedules, NASA Headquarters can also monitor mission status and coordinate field center activities to assure that a launch date will be met on schedule.

Within the contractor organizations, schedules are developed which provide information to the field centers for the major project management schedules. Internally the contractors also develop operating schedules for planning and control of production based on assemblies, sub-assemblies, and parts as defined in the work breakdown structure.